SHORT PACKET STRUCTURE FOR ULTRA-RELIABLE MACHINE-TYPE COMMUNICATION: TRADEOFF BETWEEN DETECTION AND DECODING

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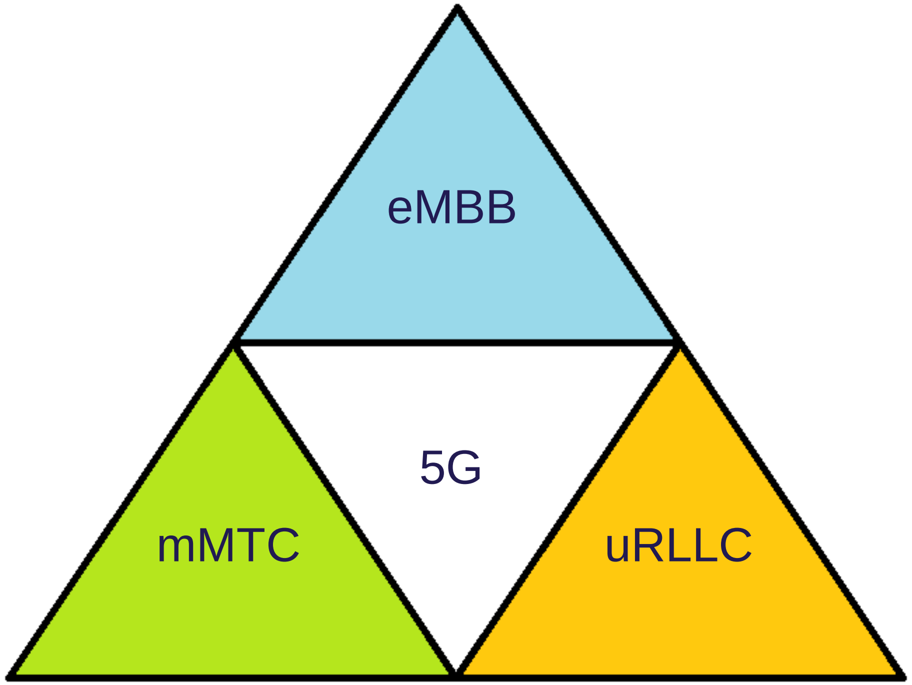
Overview

- Machine-type Communications
- Short packet implications
- System model
- Packet structure
- Analysis
- Results and conclusion

Machine-type Communications



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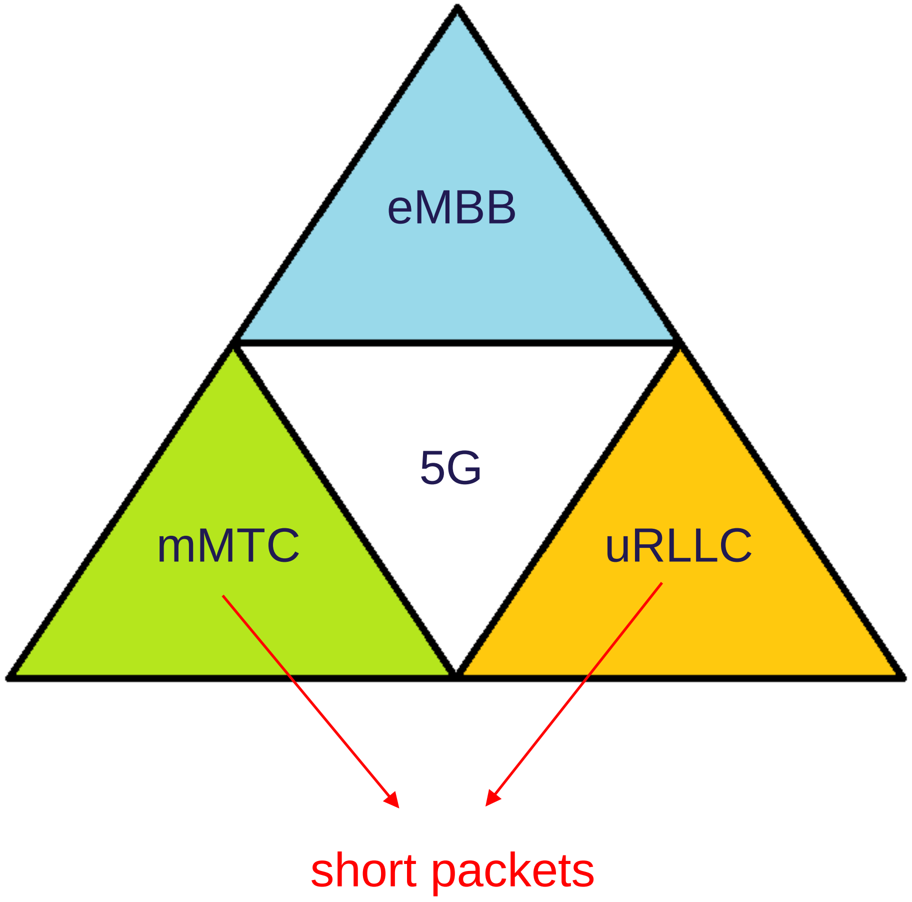

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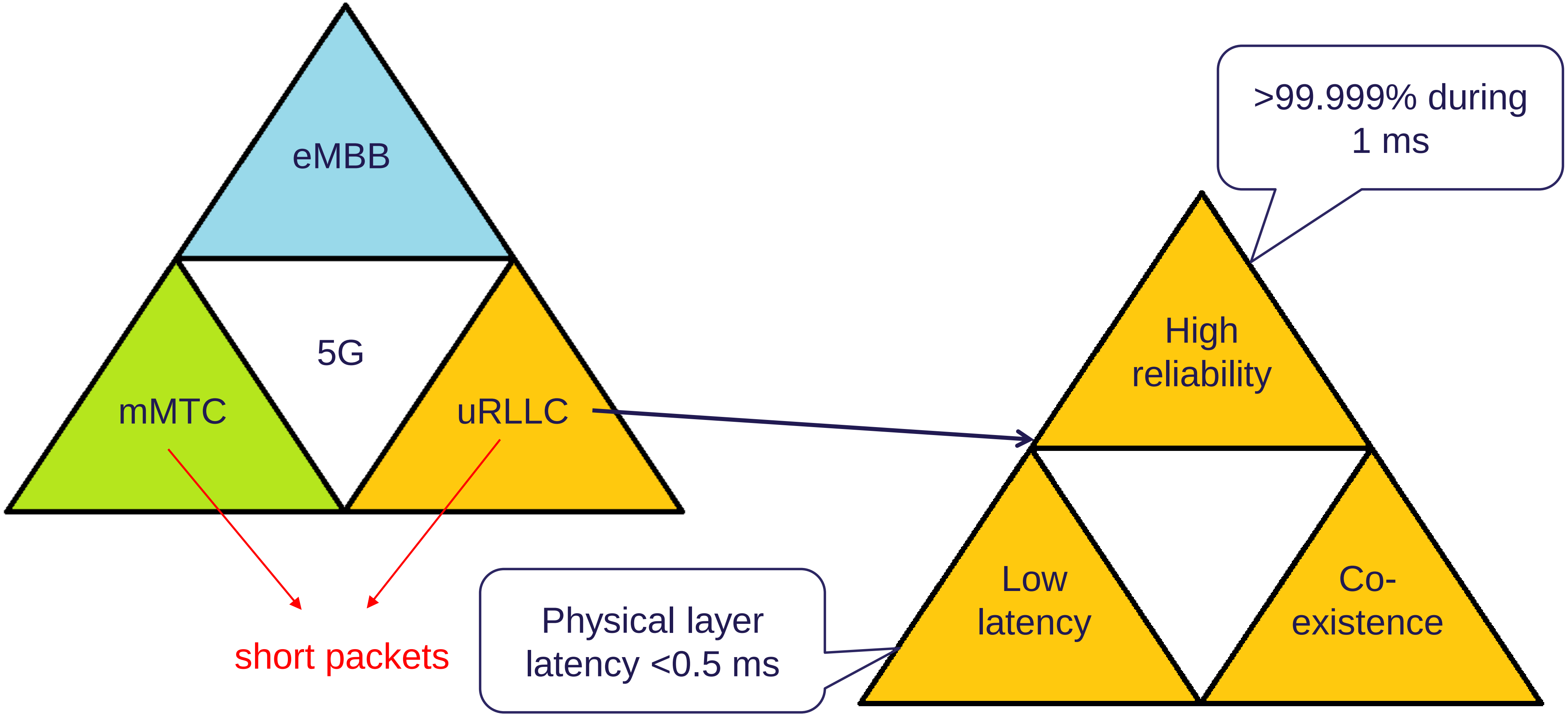

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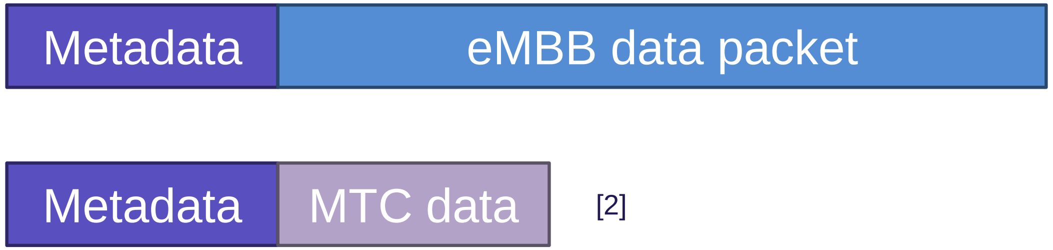
[1]: H. Ji et al., *Introduction to Ultra Reliable and Low Latency Communications in 5G*, April 2017, arXiv:1704.05565v1 [cs.IT].

Short packet implications

- Coding limitations in finite blocklength regime
- Non-negligible control information overhead
- Considerable cost of packet detection



[2]

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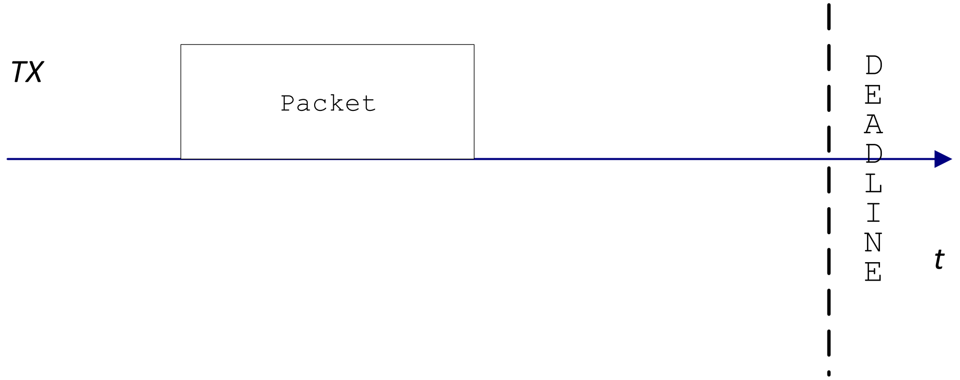
[2]: G. Durisi, T. Koch, P. Popovski, *Towards Massive, Ultra-Reliable, and Low-Latency Wireless Communications with Short Packets*, March 2016, arXiv:1504.06526v4 [cs.IT].

System model



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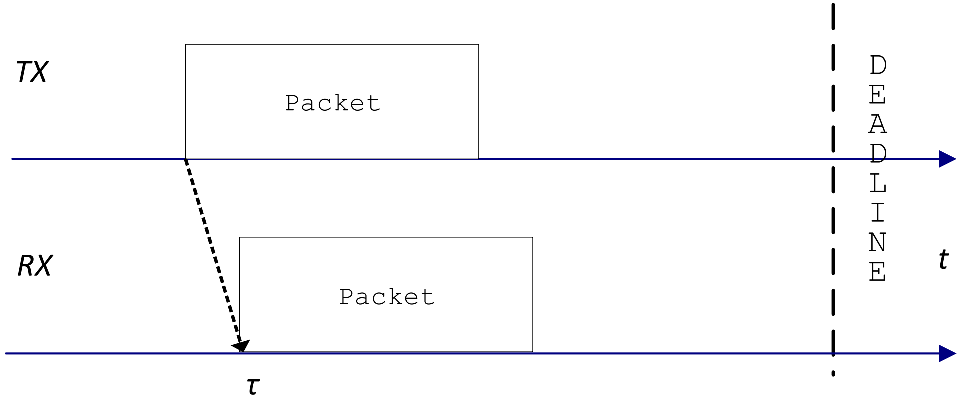

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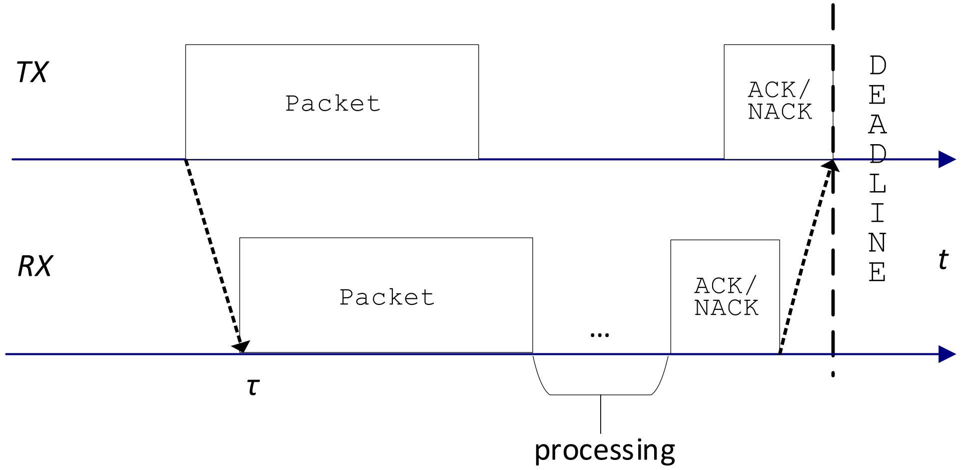

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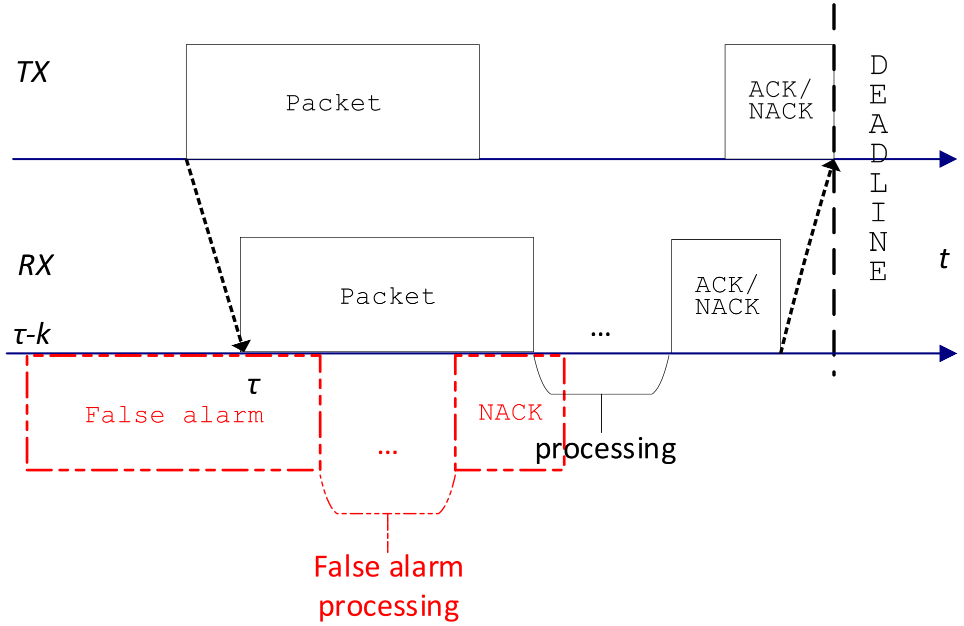

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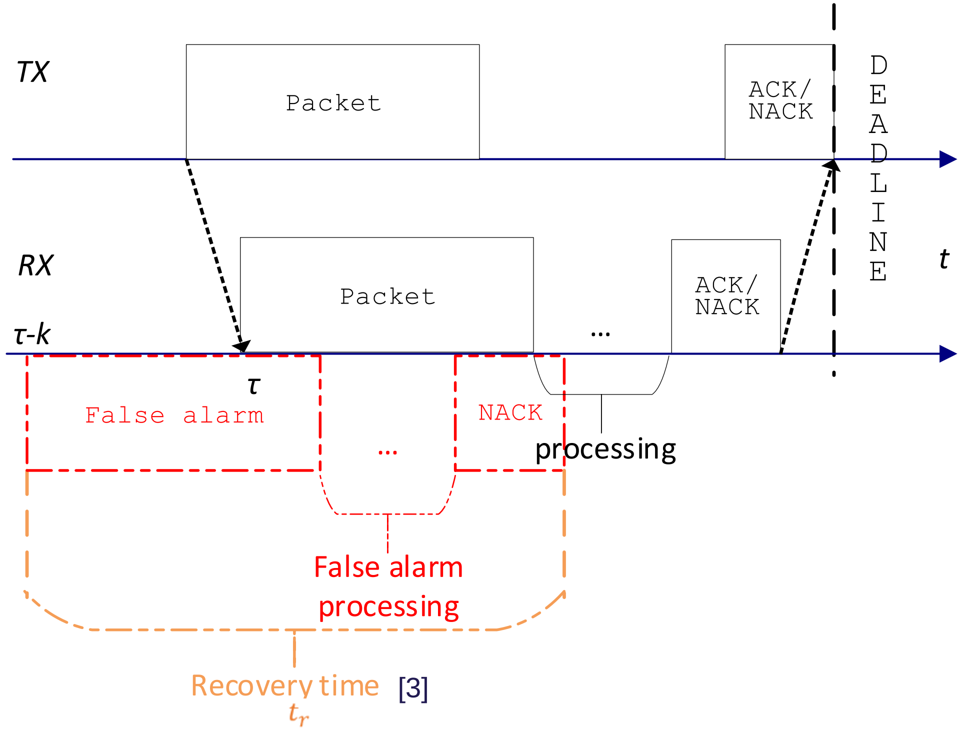

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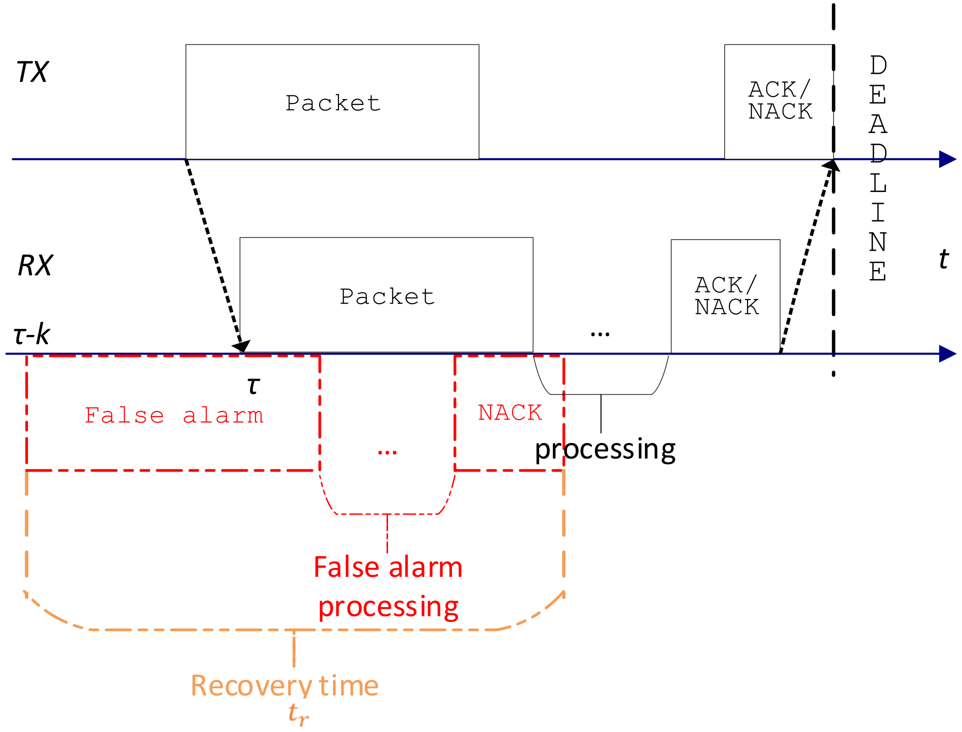
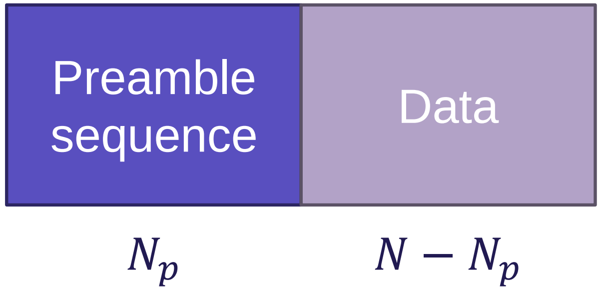
[3]: S. Nagaraj, S. Khan, C. Schlegel, M. V. Burnashev, *Differential preamble detection in packet-based wireless networks*, IEEE. Trans. Wireless Commun., vol. 8, no. 2, Feb. 2009.

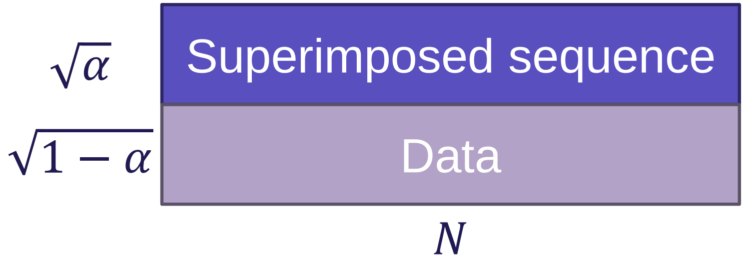
System model

- Point to point
- Data and ACK exchange with deadline
- One-shot (no retransmission opportunity)
- Unknown packet arrival time τ
- Constant channel and known by TX & RX



Packet structure





- Zadoff-Chu detection sequences

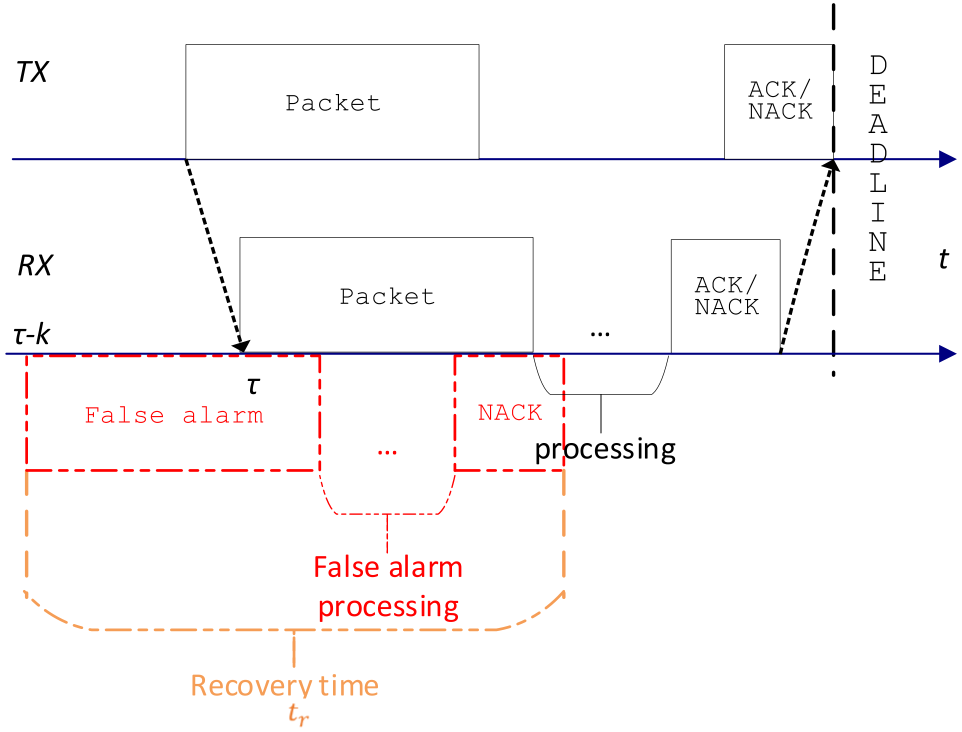
$$\mathcal{R}_{Y,\tau-k} = \Re\left[\sum_{j=0}^{N_t-1} p_j^* Y_{j+\tau-k}\right] > \Delta$$

- Small N -> finite blocklength regime
- Spherical Gaussian codebook

System model (ctd.)

- Ideal (N)ACK reception and fixed structure
- Sequential receiver operation

$$P_e = 1 - (1 - \epsilon_d)(1 - \epsilon_D)$$



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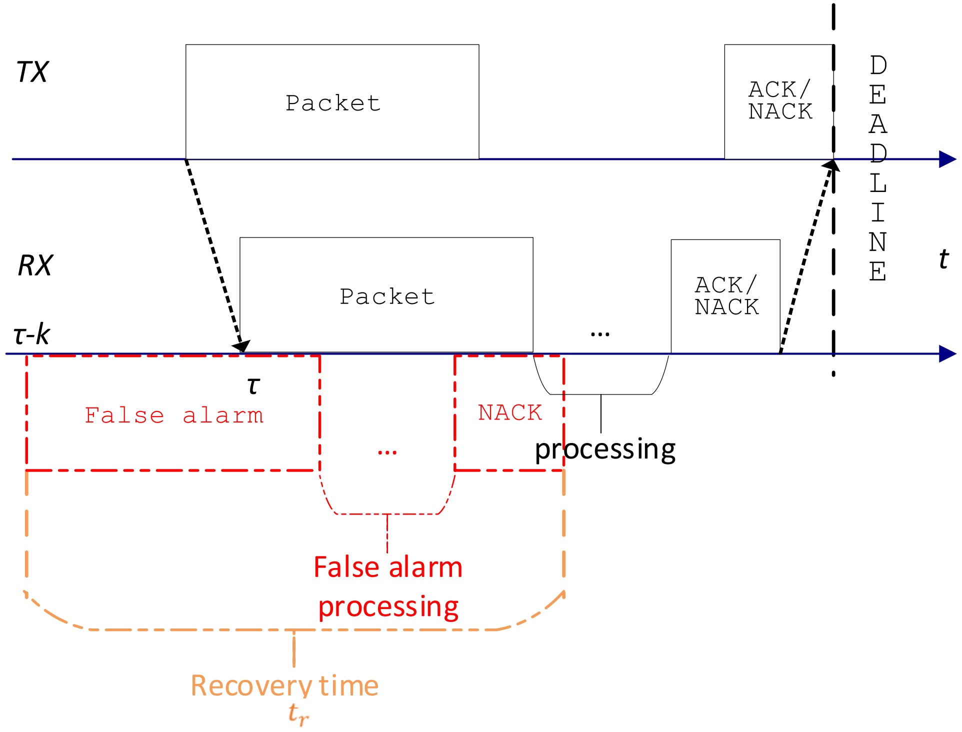
Decoding error

Detection errors:
- False alarm
- Misdetection



Analysis

- PER upper bound

$$P_e \leq \Pr[\varepsilon_{\mathrm{FA}}] + \Pr[\varepsilon_{\mathrm{MD}}] + \Pr[\varepsilon_{\mathrm{D}}]$$

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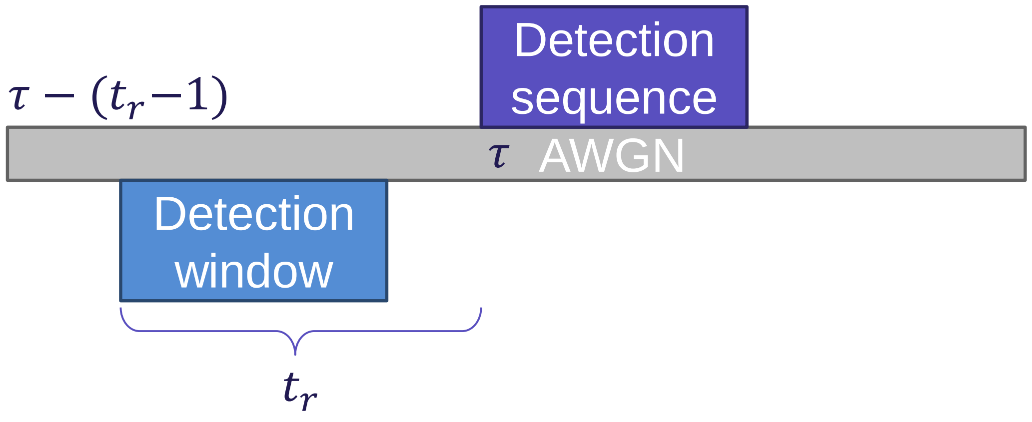

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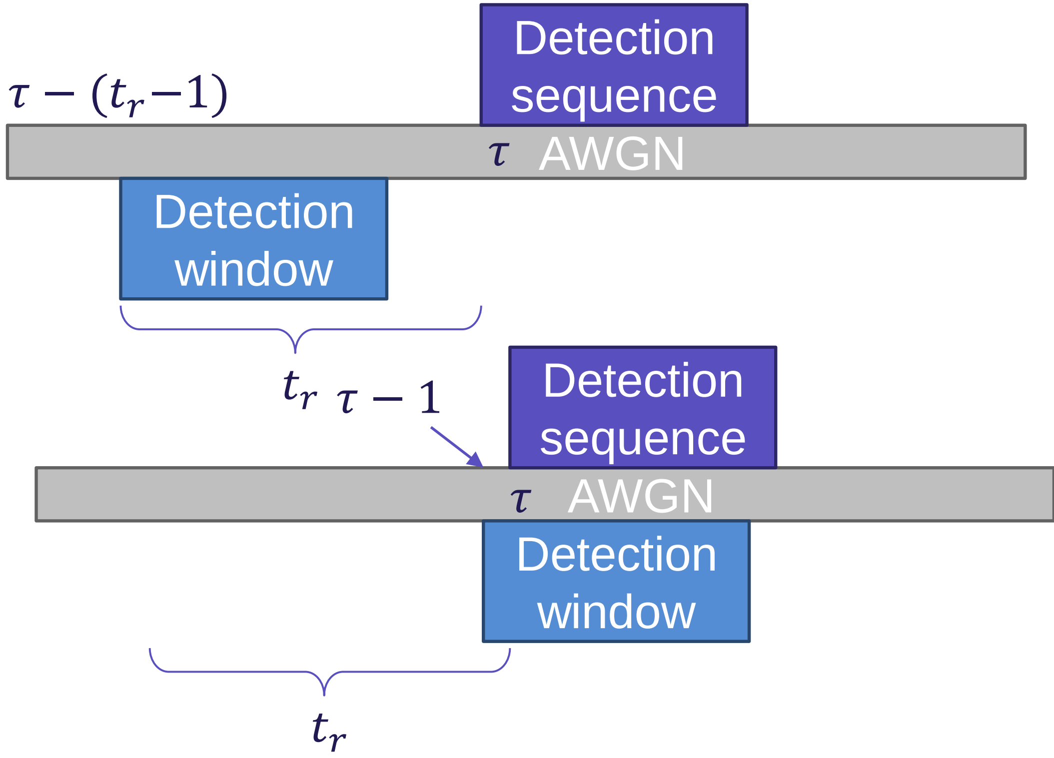

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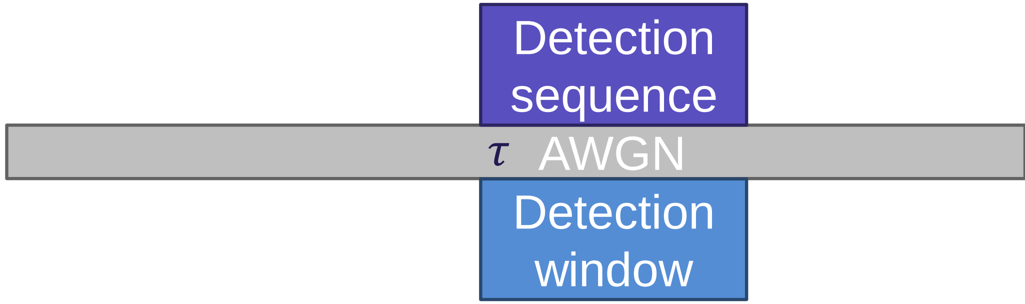

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- Decoding error

$$\epsilon_D(N_c, P) = \mathrm{Q}\left(\frac{2N_c C(P) - b + \frac{1}{2}\log_2 2N_c}{\sqrt{2N_c V(P)}}\right)$$ [2], [4]

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[4]: Y. Polyanskiy, H.V. Poor, S. Verdú, *Channel coding rate in the finite blocklength regime*, IEEE Trans. Inf. Theory, vol. 56, no. 5, April 2010.

Time-multiplexed preamble

- A false alarm can occur at any $k \in \mathcal{S}_{FA} = \{1, \ldots, t_r - 1\}$.

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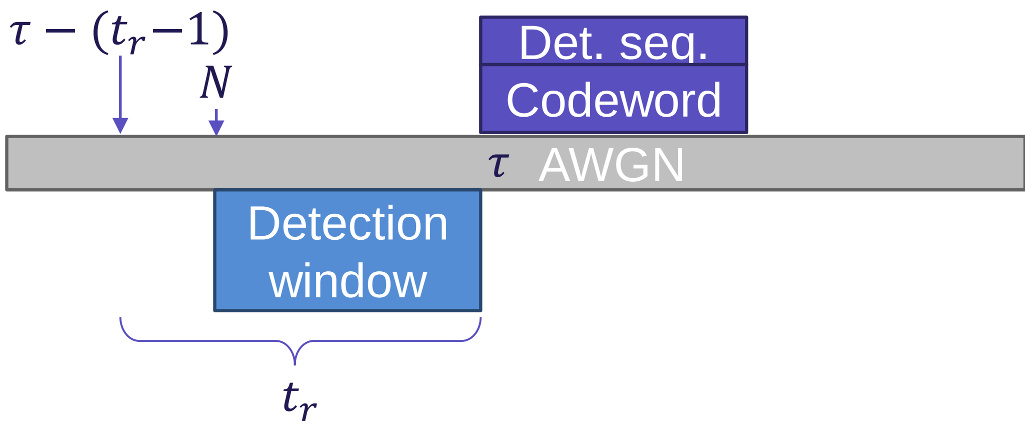
- The probability of misdetection

$$\Pr[\varepsilon_{MD}] = \mathrm{Q}\left(\frac{\mu_{\mathcal{R}_{Y,\tau}} - \Delta}{\sigma_{\mathcal{R}_{Y,\tau}}}\right)$$

Superimposed sequence

1. Noise inflicted false alarms when $k \in \mathcal{S}_{FA1} = \{N, \dots, t_r - 1\}$

$$\Pr[\varepsilon_{FA1}] \leq (t_r - N)\mathrm{Q}\left(\frac{\Delta}{\sigma_{\mathcal{R}_{Y,FA1}}}\right), \text{ where } \sigma^2_{\mathcal{R}\,Y,FA1} = \frac{N}{2}.$$



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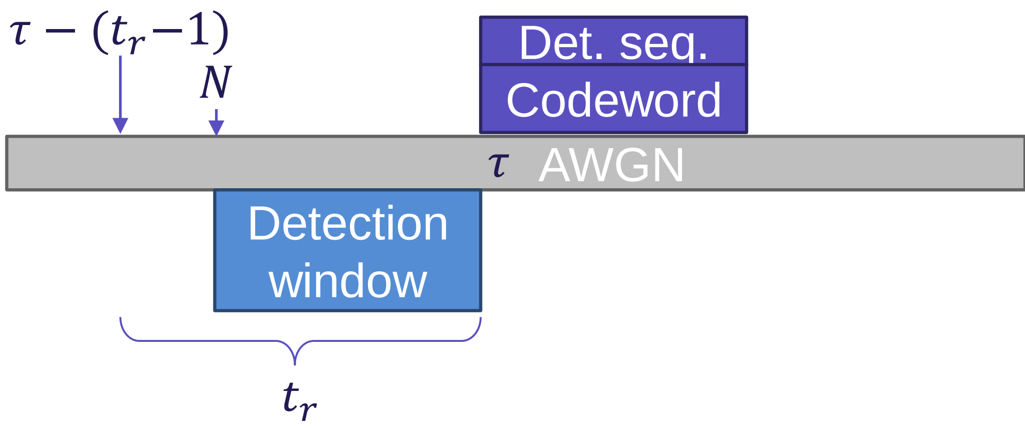
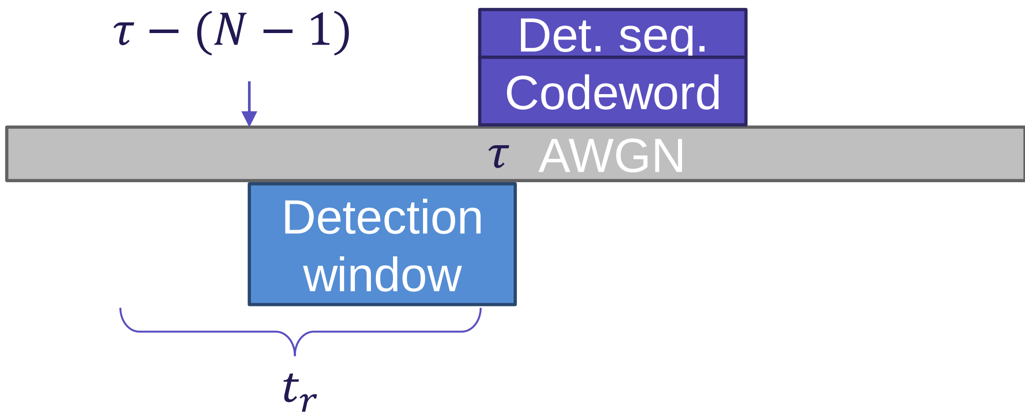


2. Partial correlation inflicted false alarms when $k \in \mathcal{S}_{FA2} = \{1, \ldots, N - 1\}$

$$\Pr[\varepsilon_{FA2}] = \Pr\left[\bigcup_{k \in \mathcal{S}_{FA2}} \{\mathcal{R}_{Y,\tau-k} > \Delta\}\right] \approx \sum_{k=1}^{N-1} \mathrm{Q}\left(\frac{\Delta - \mu_{\mathcal{R}_{Y,FA2}}(k)}{\sigma_{\mathcal{R}_{Y,FA2}}(k)}\right).$$



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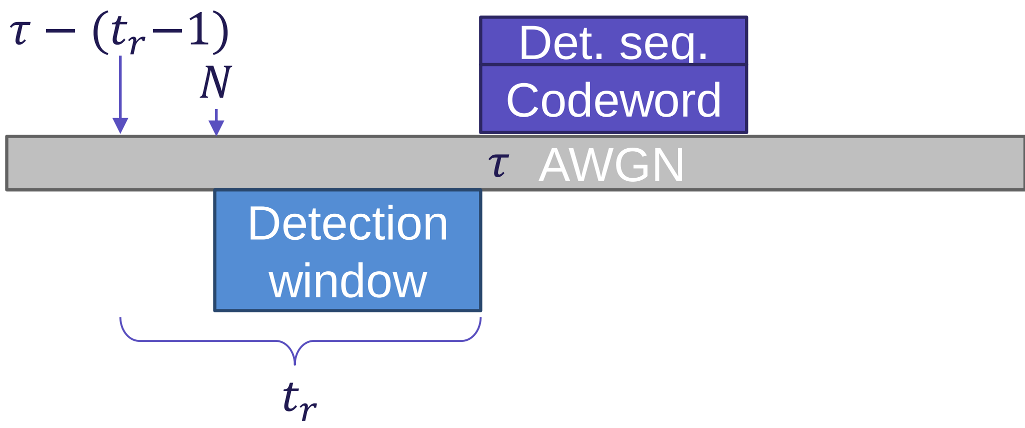

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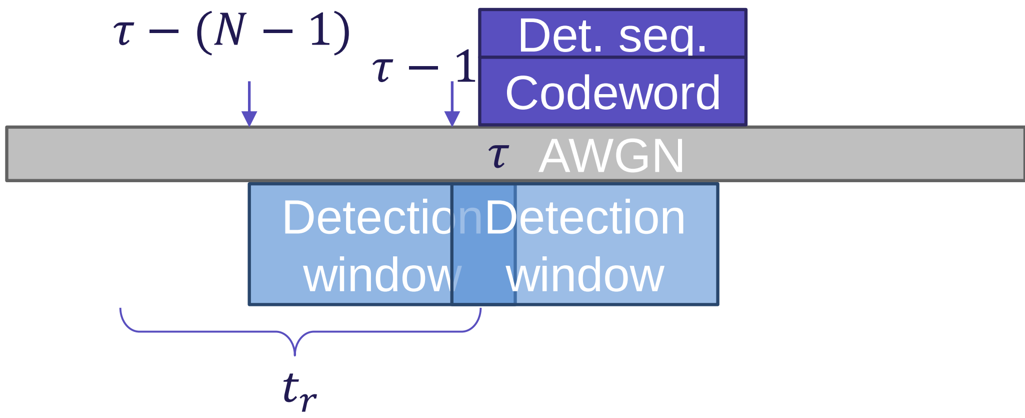

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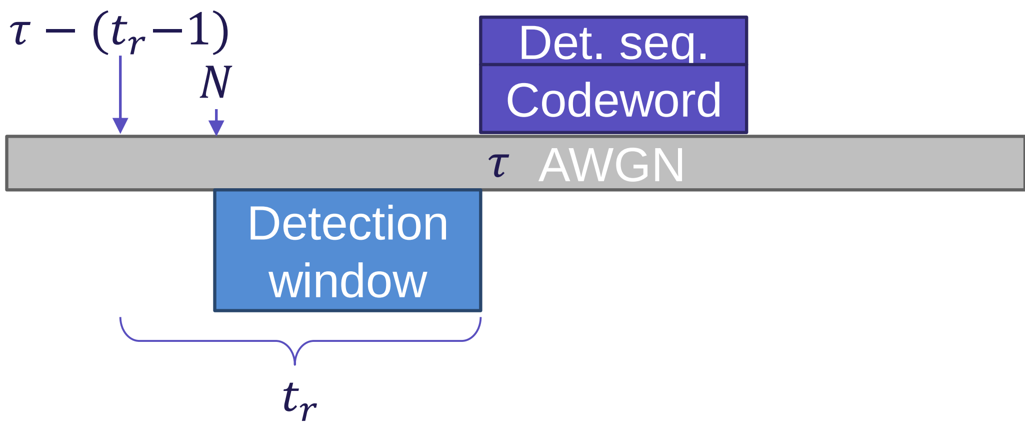

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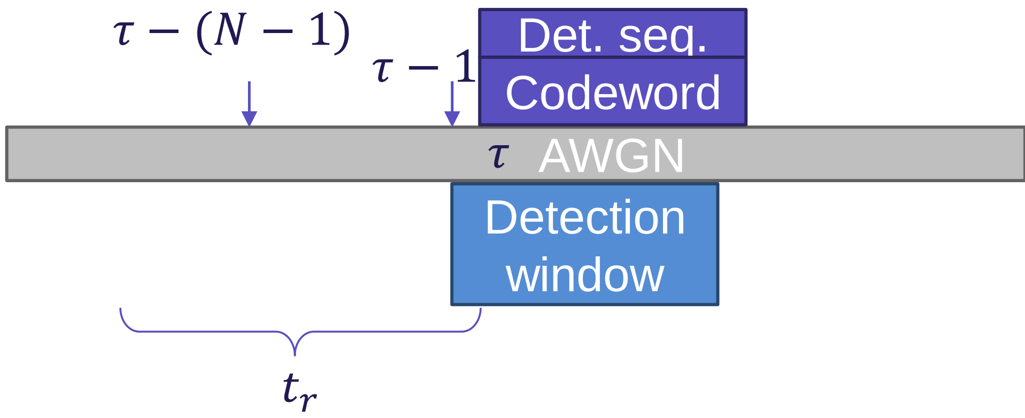

and $\sigma^2_{\mathcal{R}\,Y,FA2}(k) = \frac{N}{2} + \frac{N-k}{2}(1 - \alpha)P$

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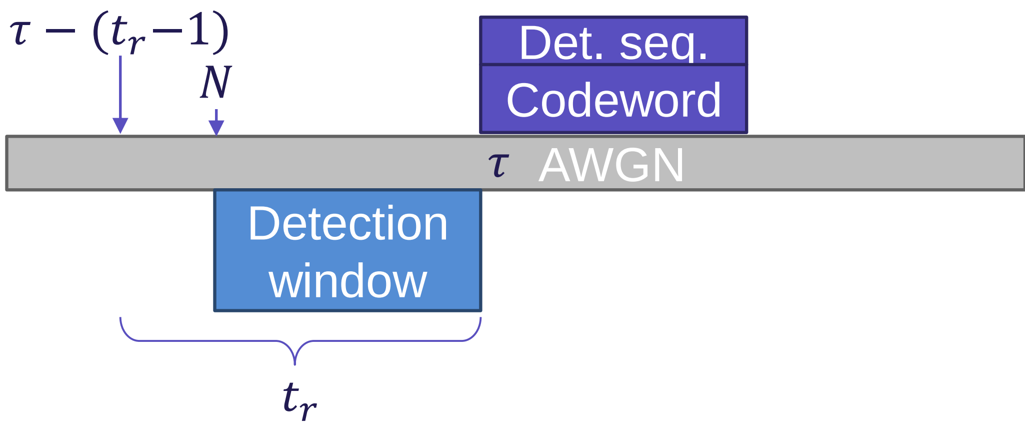

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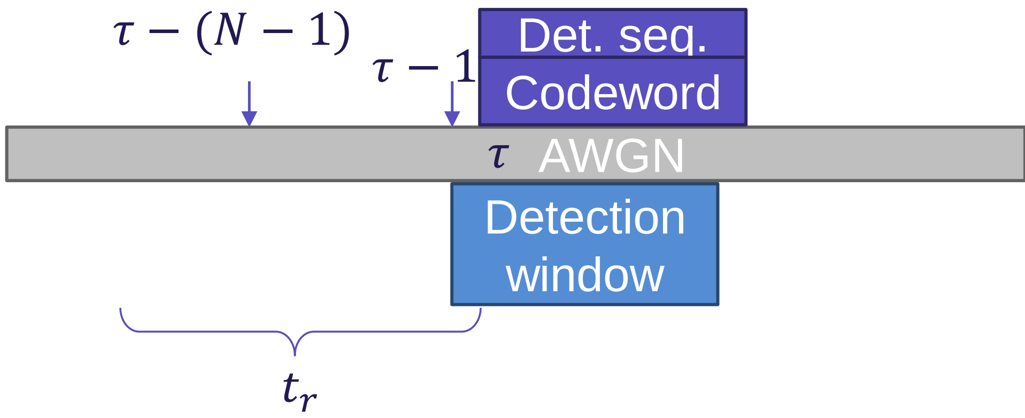

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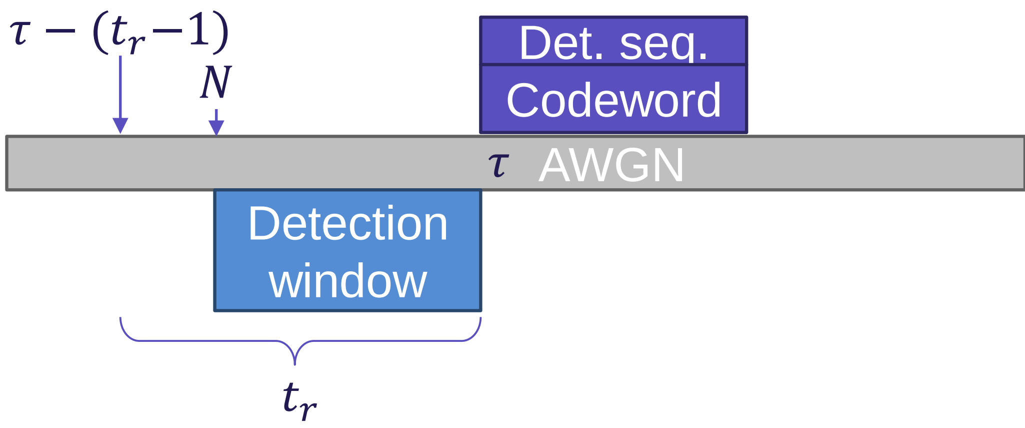

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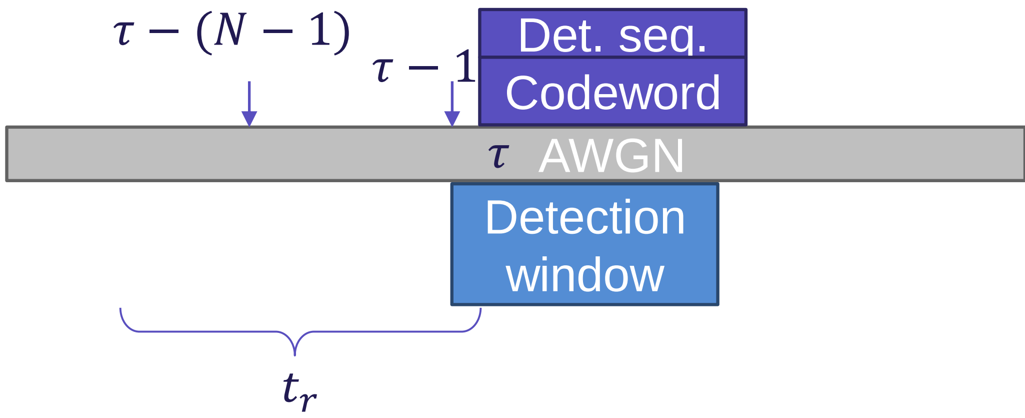

3. Misdetection probability

$$\Pr[\varepsilon_{MD}] \approx \mathrm{Q}\left(\frac{\mu_{\mathcal{R}_{Y,\tau}} - \Delta}{\sigma_{\mathcal{R}_{Y,\tau}}}\right)$$

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Packet structure optimization

- Formulate the problem as a minimization of the upper bounds on the PER

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Superimposed case: $$\min_{\substack{\alpha \in (0,1) \\ \Delta \geq 0}} \overline{P_e^{\mathrm{SI}}}(\Delta, \alpha, N, P)$$

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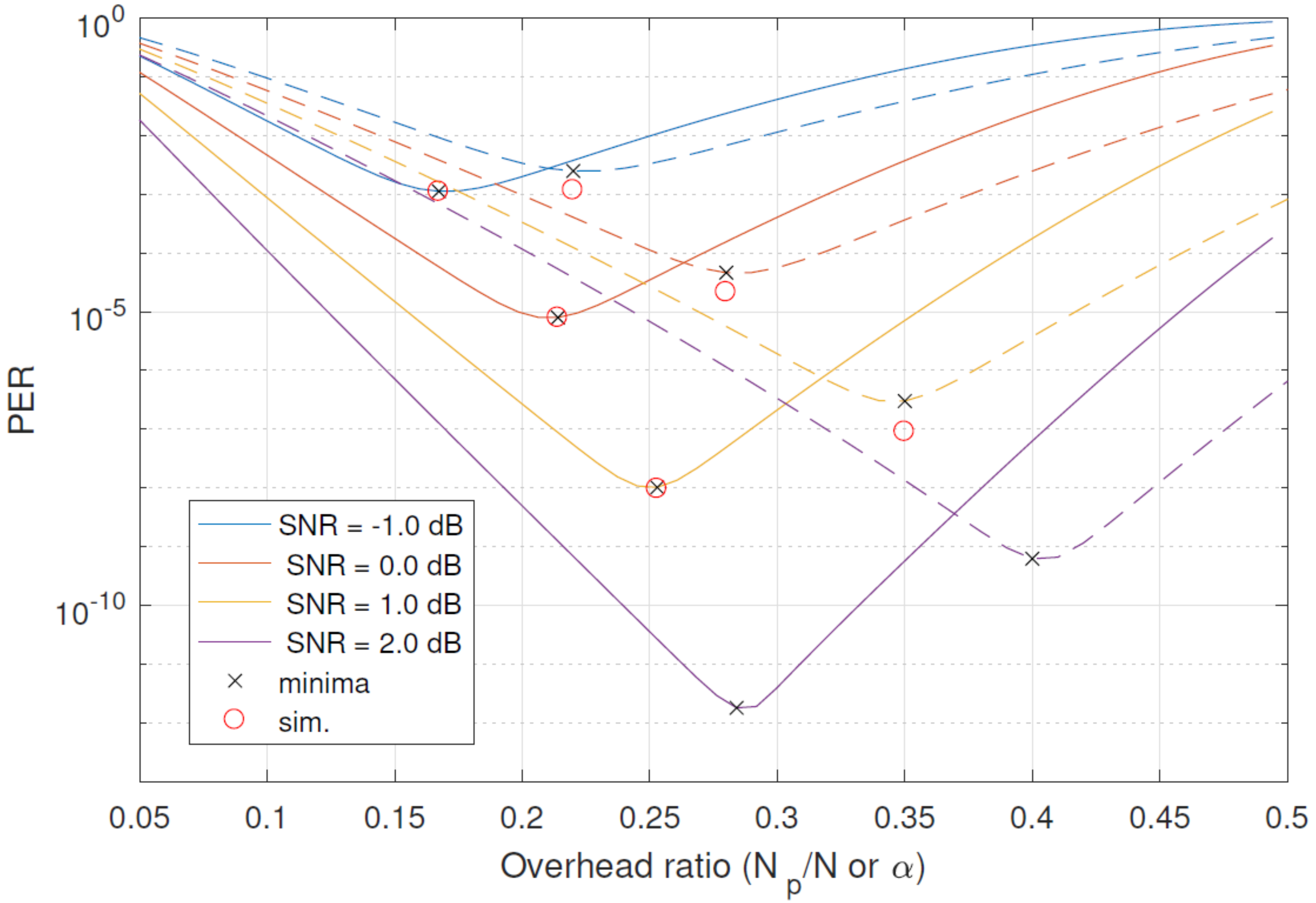
Numerical results

preamble

superimposed



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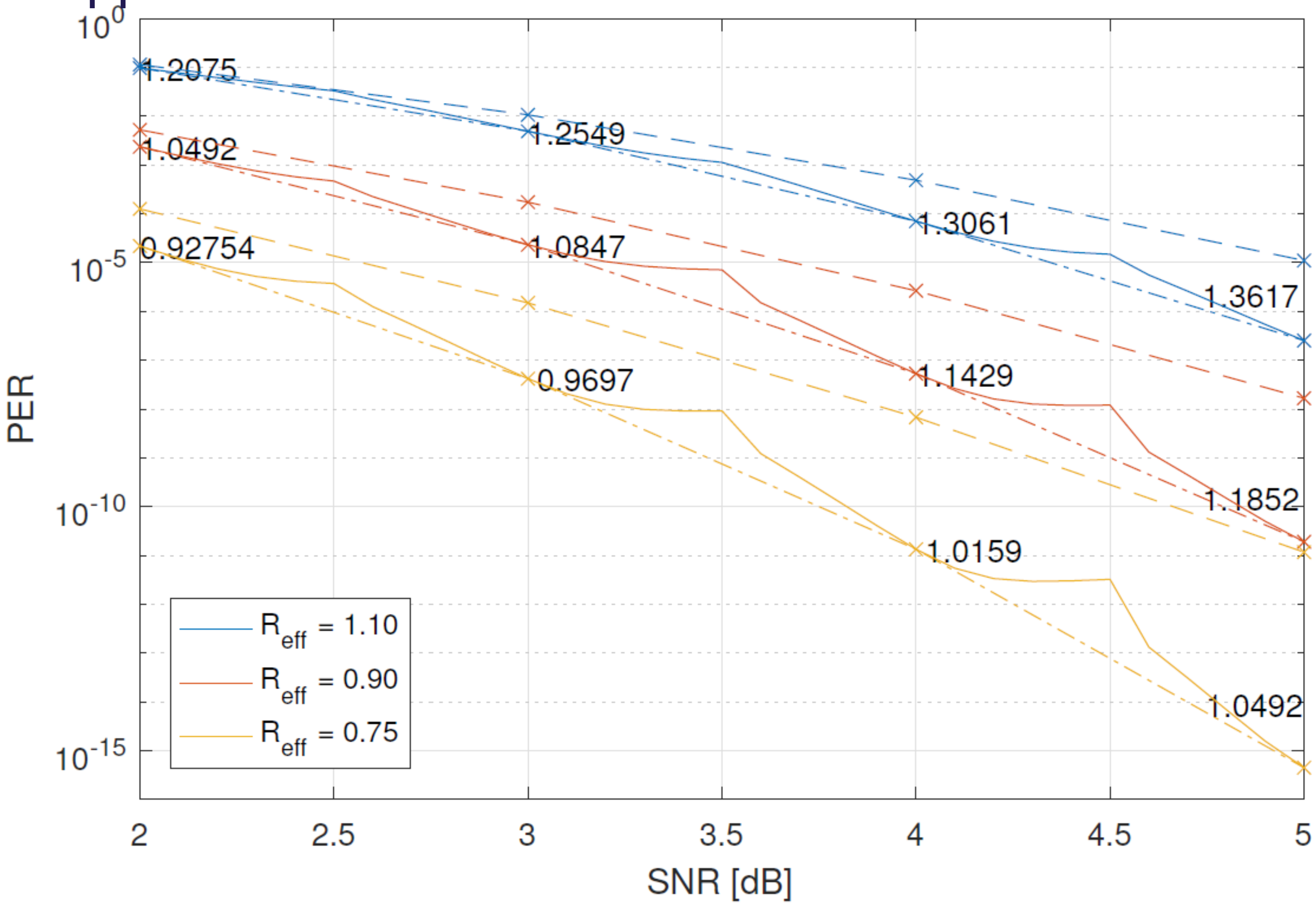
$b = 128, N = 257, t_r = 1.1N$

Optimal vs. pragmatic approach

Optimal SI

Optimal preamble

Pragmatic preamble



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$$b = 128, R_{eff} = \frac{b}{N}, t_r = 1.1N$$

Conclusion and further work

- Showcase the importance of considering overhead when transmitting short packets
- Compared two packet structures
- Provided an upper bound and an approximation for evaluating short packet error probability

- Include ACK error probability and ACK structure
- Improve detection metric to take into account the received signal energy

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THANK YOU!

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